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DISCUSSION OF TREATMENT OF FOUNDATIONS FOR LARGE DAMS BY GROUTING METHODS

(*Published in February, 1950*)

By A. Mayer; V. L. Minear; Byram W. Steele; James B. Hays; and A. W. Simonds, Fred H. Lippold, and R. E. Keim

POWER DIVISION

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DISCUSSION

A. MAYER,[4] M. ASCE.—The "Synopsis" of this paper contains the statement:

> "One important method of foundation treatment, chemical grouting, is not discussed in this paper since it is not as yet generally used by the Bureau of Reclamation (USBR) * * *."

and, in the "Summary," the authors state:

> "Chemicals will penetrate smaller openings than cement but as yet chemical grouting is in the development stage and has not been proved on a large scale."

Testimony presented at the 1948 meeting on large dams in Stockholm, Sweden, does not support the latter statement as applied to practice outside the USBR. At that meeting the writer described the work on the Genissiat Cofferdam and on the Lac Noir Dam in France.[5] E. Ischy,[6] general manager of the Soletanche Company, discussed the grouting procedure at the Castillon Dam, in France, where chemicals were used in combination with cement or clay. Because of these cases and other cases which have occured since the writer sincerely believes that grouting with chemicals is no longer in the experimental stage and can be applied reliably wherever necessary.

Aside from the question of chemical grouting, there is a general method to be followed in grouting procedure which, in the writer's opinion, the authors did not make quite clear. The problem, as they state it, is to stop percolation in the foundation material, be it rock or pervious alluvial material. In order to stop the flow, one must use a grouting material that will remain in the voids without being washed away either during the grouting process or afterward, when the reservoir has been filled. The nature of the grout will thus depend on the nature of the voids or cavities to be filled, and on the velocity of the percolating water. The most important quality of the grout will be its stability—the suspension must remain as a suspension until it has arrived at its setting point. This is particularly true when Portland cement is used because cement suspensions are generally not stable.

The writer, therefore, always recommends an addition of clay (bentonite, if possible) to the cement grout to insure the stability of the suspension during the pumping process. If the voids are very large, the proportions of cement, clay, and (eventually) sand are a matter of circumstance, to be determined in

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NOTE.—This paper by A. W. Simonds, Fred H. Lippold, and R. E. Keim was published in February, 1950. The numbering of footnotes in this Separate is a continuation of the consecutive numbering used in the original paper.

[4] Inspecteur Général des Mines, Ministère de l'Industrie et du Commerce, Paris, France.

[5] "Dispositions les Plus Recentes pour Empecher la Formation des Renards," by A. Mayer, *Question No. 10, Report No. 22*, International Comm. on Large Dams, Paris, France, 1948.

[6] "Barrage de Castillon, Lutte contre les Erosions Souterraines," by E. Ischy, *Question No. 10, Report No. 36*, International Comm. on Large Dams, Paris, France, 1948.

each separate case according to existing conditions. In the case of the Castillon Dam, the object of the grout was to enable a fissured, calcareous mass to be used as an abutment for an arch dam. The cavities were so large that cement alone would not have filled them. The percentages of cement, sand, and clay necessary to obtain a stable suspension were determined in the laboratory. The resulting product was so stable that it could be pumped into a regular water stream, remain there until the cement had set, and still yield the desired bearing power to the mass.

Stable suspensions can also be obtained with cement and small admixtures of clay by commercially patented processes involving pressure grouting of sand-cement suspension. If resistance is not required, chemically treated clay can also be used, the object of the treatment being to obtain a progressive increase of the viscosity of the grout that will thus be stable against water pressure. The tests made during the grouting process at Genissiat, between two lines of clay grouted holes, 12 ft apart, showed that both screens were watertight up to a pressure of 9 kg per sq cm (128 lb per sq in.), the maximum that could be applied without breaking through the alluvial strata.

A choice between different methods will be determined by the size of the voids: (1) In alluvial sand (from 0.1 mm to 0.2 mm) it will be necessary to grout with chemicals or an asphalt solution; (2) in sand larger than 0.2 mm, a chemically treated clay can be used with or without Portland cement; and (3) if the voids are unusually large, sand can be incorporated in the grout to advantage.

Great care must be given to the nature of the chemical additions necessary to keep the clay in suspension, and to the chemicals used for the grouting process. If mineral wells, natural salts, or sea water are encountered, the conditions of set are completely changed and awkward incidents may occur. Most of these types of incidents have already been encountered and experience has shown that close cooperation between the laboratory and the field will solve most of the problems that arise.

V. L. MINEAR,[7] M. ASCE.—The literature on foundation grouting is enhanced by the publication of this paper, which summarizes what has been found to be good practice in the construction of twenty or more large dams since 1930. The paper is full of many small details each of which has been learned "the hard way" on some project. The difference between an excellent job and a mediocre job depends on the observance of these small details.

Great progress has been made in grouting equipment and methods since 1930. It is "a far cry" from the old "air pot" pneumatic injector to the modern grout pump with its special pistons, liners, valves, valve seats, packing, etc. Likewise, there is a great difference between the reuslts accomplished by some temporarily idle concrete inspector, who mixed up some cement and water and blew it down a hole in the ground, and today's foundation engineer who, with a clear understanding of subsurface conditions given him by the engineering geologist, proceeds to correct existing defects rationally.

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[7] Engr., Corps of Engrs., Office, Chf. of Engrs., Washington, D. C

No comparable progress has been made in the selection and improvement of materials for grouting during this period. Many engineers question the durability of neat cement grout placed with the extremely high water-cement ratios (as much as 150 gal per bag) currently used, even if all the surplus water actually were extruded by pressure. The experience of the United States Bureau of Reclamation with uplift on some of its older dams, the foundations for which were grouted, should be enlightening. One of the primary purposes of curtain grouting is to reduce uplift. Conversely, if the curtain deteriorates through the solution of the hardened cement, then uplift should increase progressively with age as the grout deteriorates.

In 1935, D. W. Cole,[8] M. ASCE, stated:

> "The suggested limitation of benefits by the cementation process alone, opens a further field of usefulness for cement chemists and testing laboratories. A safe and reliable means of sealing the voids in otherwise completed masonry structures is needed, in order to make them virtually impermeable by water. This problem involves the production, at moderate cost, of a substance of demonstrable durability, having the property of setting or hardening in place without loss of volume or injurious reaction to any masonry constituent, and which can be carried in solution in water under pressure while maintaining a fluidity equal to, or greater than, water itself."

In the opinion of the writer the need expressed by Mr. Cole still exists for foundation grouting where the use of grouts with excessively high water content is considered a makeshift of doubtful value.

BYRAM W. STEELE,[9] ASSOC. M. ASCE.—The data on grouting equipment, materials, and procedures, presented in this paper, are interesting and valuable. The paper serves to revive curiosity as to the why's and wherefore's of ungroutable places that should be filled with grout of low water-cement ratio.

High water-cement ratios are not conducive to impermeability, durability, or satisfactory strengths in concrete. The same statement can be made relative to high water-cement ratios in Portland cement grout, except that the principal objectionable feature in such a grout is that it is pervious. Leaching will eventually take place and gradually transform an impervious area into a pervious one.

Under the heading, "Cement-Grout Mixtures," the authors state:

> "For tight seams or cracks in the rock, ratios of 20:1 have been used. The usual grout mixes are proportioned within the limits of 1:1 and 10:1. Thin grout placed under sufficient pressure to force out the excess water will form a hard, durable film."

The last sentence of this quotation caught the writer's eye on first reading and reminded him of some grouting experience in connection with mass concrete

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[8] "Stabilizing Constructed Masonry Dams by Means of Cement Injections," by D. W. Cole, *Transactions*, ASCE, Vol. 101, 1936, p. 743.

[9] Special Asst., Civ. Works Div., Office, Chf. of Engrs., Dept. of the Army, Washington, D. C.

research for Hoover Dam (Arizona-Nevada) about 1930, in which it was reported that:[10]

> "* * * For cracks of the order of .05 in. a grout in which the ratio of water to cement is as 75 to 100 by volume gives the most desirable film. A water-cement ratio of 1.00 contains too much free water that cannot be forced into the concrete or otherwise dissipated."

It is admitted that, if the excess water can be forced out and the resulting grout consolidated, a film could be produced that would be hard and durable, but this does not occur in too many instances and the result is a chalky grout that is permeable.

Development work in grout mixtures has been conducted over the intervening years in connection with oil well drilling, and especially in connection with repairs to tunnel linings and similar instances of deterioration in concrete. Newer patented processes have marked a very definite contribution to the science and technique of better grouting methods, but some basic research work still remains to be done before it will be possible to make use of the low water-cement ratios that are necessary to produce impermeability, even in grout.

In the early days of grouting contraction joints in dams, it was found necessary to screen all the cement through a 200-mesh sieve to produce a grout that would be devoid of large particles of cement and sufficiently fluid to fill contraction joints with from $\frac{1}{16}$-in. to $\frac{1}{8}$-in. openings. It is an extremely expensive and laborious matter to move cement through a 200-mesh sieve even if the operation is all done by machinery and more or less automatically. There are various methods of disposing of the oversize particles of cement, but reliable information relative to ways and means of producing flowable grout with a low water-cement ratio, in fine cracks, is lacking. Therefore, it appears that it would be desirable to do some extensive basic research on grouting materials of various kinds, including Portland-pozzolanic blends of cement. Particle size and gradation of all material should also come in for a thorough investigation. This statement is made because of the obvious advantages relative to nonsegregation that accrue to the grout mixtures that have been perfected by at least one commercial concern; but the so-called oversize particles in the cement and in the fly ash still present the same old difficulties found in straight Portland cement grouts. It is extremely difficult to do a satisfactory job of grouting fine seams of the order of 0.02 in. or less under moderate pressures such as can be used in contraction joints or in foundation areas immediately adjacent to the surface. Clusters of coarse particles ($\pm$ 60 microns) plug the cracks and prevent the creation of a grout film of acceptable consistency.

It thus appears that the fineness and gradation of a type III[11] (high early strength) cement which has relatively few particles of + 60 microns might be more satisfactory for grouting fine seams than cements of types I and II.[11] If it can be proved that there is a definite advantage in the use of finenesses similar to, or finer than, the fineness of a type III cement, it is suggested that the cement and the admixture used in the commercially produced grout be ground to a

[10] "Mass Concrete Research for Hoover Dam," by Byram W. Steele, *Proceedings*, A.C.I., Vol. 29, 1933, p. 313.

[11] "Long-Time Study of Cement Performance in Concrete," by William Lerch and C. L. Ford, *Proceedings*, A.C.I., Vol. 44, 1948, p. 763.

fineness similar to, or finer than, that of type III cement, and that further tests be conducted with this particular grouting procedure.

To summarize: It is believed that to produce relatively impermeable grout films under moderate pressure (50 lb per sq in.), and especially for seams as fine as about 0.02 in., it is mandatory that water-cement ratios of the order of 10 to 1 and more be reduced to as near 1 to 1 as is practicable. To accomplish this objective, finer-ground cementing materials and blends should be substituted for those normally used and this refined grout should be tested in comparison with the product now in common use.

JAMES B. HAYS,[12] M. ASCE.—All the basic information, as well as the operational details, for treating, tightening up, or "firming" foundations for dams, is contained in this paper. The same procedure is also suitable for other structures. The authors have carefully described certain features of the mechanical system, particularly the pumps, that are a "must."

During the late 1920's, the writer was confronted with instructions to do some high-pressure grouting on the Calderwood (Tenn.) dam site. The literature of that day contained very little information except on a certain patented process. At that time the engineers had been using both the vertical and horizontal grout machines with an air pressure of 100 lb. A pump was tried and the old horizontal mixer type of grout machine was used to mix the batches which were dumped into a large tub and stirred by hand, thus supplying a steady flow for the pump. The early type of valves, liners, and packing provided caused no end of trouble.

When the writer went to Boulder Dam (Arizona-Nevada), it was found that the contractors had learned how to handle the pump troubles by rubber valves and pistons. However, they had a cumbersome method of mixing and measuring water. By a combination of the Boulder Dam and the Calderwood Dam methods, together with some other improvements, a really efficient and compact unit was evolved. Later similar outfits were built and used on many of the projects of the Tennessee Valley Authority where they were known as the "Boulder grout machines."

There have been instances of drainage holes drilled from a gallery, after grouting, directly into a grouted zone; as a result there was no seepage of water from the holes. However, not far downstream and continuing for some distance, several holes drilled for uplift testing showed considerable pressure under full reservoir. In general, the writer would suggest that drainage holes (see Fig. 1) be inclined more in a downstream direction, say, as much as 30°. In this way the holes should tap an ungrouted zone and relieve the upward pressure.

Under the heading, "Cement-Grout Mixtures," the use of bentonite as an admixture is mentioned. Bentonite is a dispersing agent. If it is mixed first and the cement added later there will be a minimum loss of swelling; but if the cement is mixed first and the bentonite added later the swelling will be greatly reduced.

In conclusion, the writer highly recommends this clear and factual paper to all who are concerned with grouting.

[12] Formerly Project Mgr., Morrison-Knudsen Afghanistan Co., San Francisco, Calif.

A. W. SIMONDS[13] AND FRED H. LIPPOLD,[14] MEMBERS, ASCE, AND R. E. KEIM,[15] ASSOC. M. ASCE.—The discussion by Mr. Mayer presents valuable information regarding grouting with chemicals and other materials. It is true that chemical grouting has been accomplished successfully on some projects, chiefly in Europe; however, its use for grouting foundations of dams has not become widespread in the United States. The chief objections to chemical grouting, using sodium silicate as one of the ingredients, are the high cost of the materials and the tendency of the grout to shrink and disintegrate if it is allowed to dry out during periods of low reservoir level. The grout does not return to its original condition when it is again wetted. Certain resin plastics may have more stable qualities, but they are also expensive. Until a low cost chemical grout having foolproof qualities is available, the writers feel that there is opportunity for further development in chemical grouting materials.

The writers agree with Mr. Mayer's statement that the addition of clay or bentonite to cement grout will improve the pumpability of the mixture by keeping the cement in suspension. The use of clay or bentonite is particularly beneficial when grouting against flowing water and when various bulking materials are needed in the grout for stopping leaks. On one occasion, when grouting against a leak beneath the cofferdam during the construction of Grand Coulee Dam in Washington, a grout mixture of the following composition was used:

Ingredients	Quantity
Portland cement (cubic feet)	2
Sand (cubic feet)	6
Lump bentonite (pounds)	50
Sawdust (cubic feet)	8
Shavings (cubic feet)	10 to 16

The foregoing ingredients were mixed thoroughly in the dry state and the following were added:

Ingredients	Quantity
Water (cubic feet)	8 to 10
Pulverized bentonite (pounds)	30

After the second part of the batch was added and the whole thoroughly mixed, the resulting product had a volume of about 14 cu ft and resembled wet cement plaster. This grout was effective in sealing off flowing water. It is doubtful if a grout mixture containing solids of this type could have been injected without the addition of bentonite.

In the case of grouting cavities where large volumes are to be placed, the use of various filler materials with the cement is profitable. The fillers most commonly used with Portland cements are clay, rock flour, sand, and (recently) certain pozzuolanic materials. If sand alone is used as a filler, it

[13] Engr., Bureau of Reclamation, U.S. Dept. of the Interior, Denver, Colo.

[14] Engr., Bureau of Reclamation, U.S. Dept. of the Interior, Denver, Colo.

[15] Engr., J. Gordon Turnbull, Inc., Richland, Wash.; formerly Engr., Bureau of Reclamation, Denver, Colo., and TVA, Knoxville, Tenn.

should be sufficiently fine so as not to settle out of the grout stream. A fine sand from wind-blown deposits is preferred. The usual mixes for filling large voids which have been used consist of one part of Portland cement to two parts or three parts of sand or clay.

Both Mr. Minear and Mr. Hays call attention to the improvements in grouting equipment which have taken place since about 1930. Equipment failures are costly as they may result in the loss of valuable time, the loss of an expensively drilled hole, or the loss of an embedded grouting system. With modern equipment, such failures are less frequent. It is gratifying to have dependable pumps and mixers which will stand up for a reasonable period of time before needing extensive repairs.

Mr. Hays' suggestion that drainage holes be inclined more in a downstream direction is worthy of consideration. Mr. Minear asks whether leaching of grout causes high uplift pressures under dams after several years of service. To date (1950), at USBR dams on which uplift pressures have had to be reduced, additional drain holes intercepting only slight quantities of water have been effective. The small quantities of water collected by the new drains and the recleaned original drains lead the writers to believe that high uplift under older dams is not caused by leaching of the cement grout as much as it is caused by the ineffectiveness of the drain holes in tight rock. At Hoover Dam it was found that the original grout curtain had not been deep enough to cut off the water under that extremely high head. Additional deeper grouting and a new drainage system corrected the uplift pressure there.[16]

Mr. Steele questions the use of grout mixtures having high water-cement ratios. Inasmuch as a low water-cement ratio suitable for a mass concrete mix would not be pumpable under most foundation grouting conditions, the writers believe that thin mixtures are no more weakened than moderate mixtures if most of the excess water is forced out of the grout. In injecting grout at high pressures into a dry formation, some of the excess water is taken up by the absorptive properties of the ground and some is squeezed out of the grout into progressively smaller seams by the pressure applied from the pump. It has been noticed on many occasions that grout emerging from surface leaks is thicker than that being pumped into the hole. Obviously, if the foundation is wet, or if grout is being used to shut off the flow of water, there is no value in using a thin grout mixture.

Cements now available commercially are greatly improved over the cements manufactured in about 1930. The greatest difficulties encountered formerly were the presence of tramp iron and relatively coarse particles of unground clinker in the cement. Such material not only was harmful to pumping equipment, but also plugged fine seams and cracks. Cement from modern mills equipped with air separators is superior to the cement made in old style mills, in that this coarse material is rarely present.

The writers agree with Mr. Steele that further research and development are needed for materials which can be used to advantage in grouting where the maximum permissible pressure is about 50 lb per sq in.

[16] "Uplift Pressures in Concrete Dams," by Kenneth B. Keener, *Proceedings-Separate No. 25*, June, 1950.

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